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Interceptor Small Arms Protective Insert (SAPI) MANTECH Product Enhancement Test Report II

by Jeffrey A. Mears, Robert F. Monks, Robert Wolffe, and James F. Mackiewicz

ARL-CR-488 February 2002

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under contract

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Abstract

This report summarizes the work performed by Specialty Plastic Products of Pennsylvania Inc. and their subcontractor, Simula Safety Systems Inc., under the Manufacturing Technology (MANTECH) program sponsored by the U.S. Army Materiel Command and executed by the U.S. Army Natick Soldier Center. The objective of this effort was to investigate M Cubed Technologies Inc.'s siliconized silicon carbide armor material and process as an alternative ceramic component for the multi-Service Interceptor Small Arms Protective Inserts (SAPI).

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1. Introduction

As described in U.S. Army Materiel Command Acquisition Center (USAMCAC) contract no. DAAN02-98-D-5007-009, line item 1004, Manufacturing Technology (MANTECH) statement of work, the contractor "shall investigate proprietary M Cubed ceramic material and material processes that will potentially provide cost-reduction benefits to the U.S. Marine Corps." Simula Safety Systems Inc.* has identified this material as an alternate to the boron carbide (B_4C) ceramic material, which is used as the strike face on the current Interceptor Small Arms Protective Insert (SAPI) plates. This new ceramic material is a "Reaction Bonded Silicon carbide" material developed by M Cubed Technologies Inc. (M Cubed).† The new ceramic material is significantly lower in cost compared to the present hot-pressed B_4C material. The lower cost of the ceramic tile is a result of inexpensive manufacturing processes employed by M Cubed. This document will summarize the efforts involved in developing the design to meet the current Interceptor SAPI requirements.

2. SAPI Optimization Effort

2.1 Tile-to-Laminate Ratio

In order to optimize the SAPI design using the M Cubed material, we first needed to understand the relationship between tile thickness to laminate thickness as related to overall armor system areal density. Therefore, the first test series was performed to define this relationship. Since the insert areal density is a constant (in order to yield an insert of known weight) of 4.8 psf, the question here was one of tile weight (thickness) to laminate weight (number of plies). This ratio has been explored before on the baseline B_4C/Spectra Shield (SS) system, but only at a minimal effort level. The effort performed here was to fully characterize this relationship for both the threat A and B projectiles. Five tile-to-laminate ratio armor systems were tested for each projectile as outlined in Table 1. These tests were performed on a clay backing using a 28-ply 600 denier Kevlar KM2 outer tactical vest (OTV) simulant between the back face of the target and the clay block.

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*Simula Safety Systems Inc., 7822 S. 46th Street, Phoenix, AZ 85044.

†M Cubed Technologies Inc., 921 Main Street, Monroe, CT 06468.

Table 1. Tile-to-laminate ratio test series for threats A and B.

% Tile	% Laminate	Tile Thickness	Plies of Spectra Shield
50	50	0.150	90
60	40	0.180	72
70	30	0.210	54
80	20	0.245	34
90	10	0.275	17

To obtain the most useful information, this testing determined V_{50} velocities for each armor system. The resulting information was plotted on a graph (Figures 1 and 2) to visually determine the optimal tile-to-laminate ratio.

As shown in Table 1, the 60% tile/40% laminate armor system is the optimal choice for further armor system development. Even though the 50/50% system produced a higher V_{50} for the threat A projectile, the threat B testing showed a lower V_{50} for the 50/50% system. To further optimize the armor system, we then evaluated several different composite backing systems based on the 60/40% tile/laminate ratio. The results of this testing are summarized in the following sections.

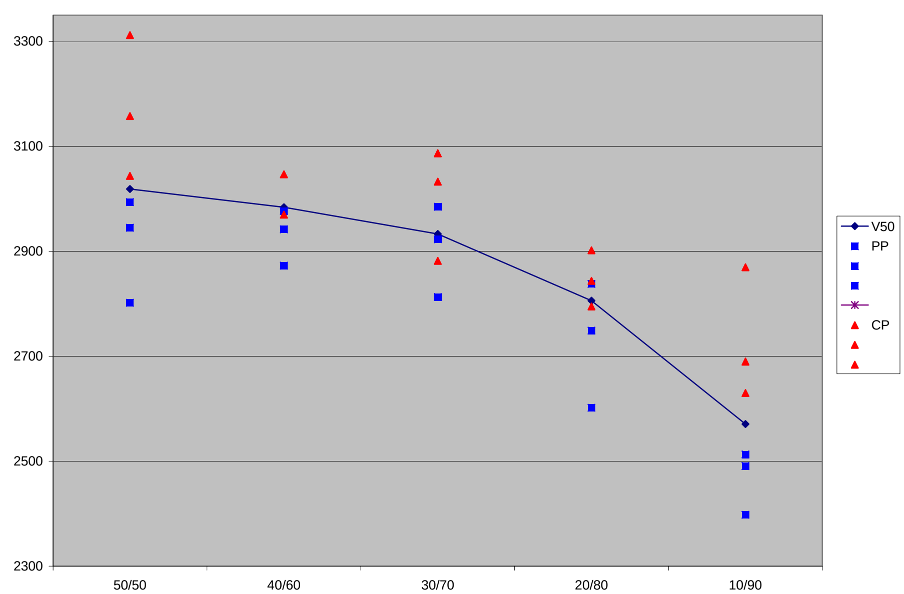

Figure 1. Threat A tile-to-laminate ratio.

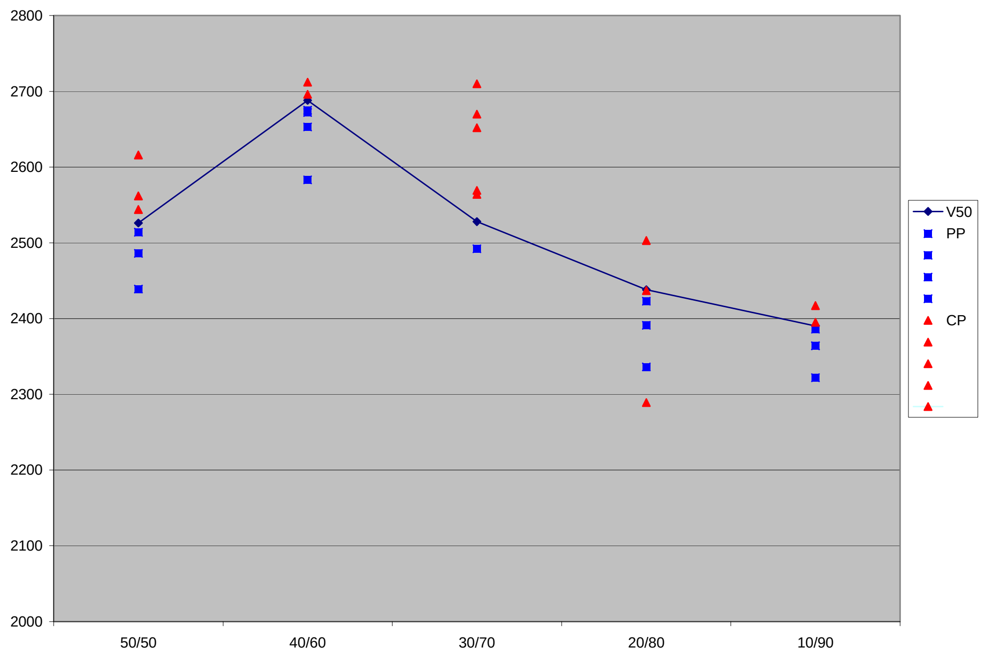

Figure 2. Threat B tile-to-laminate ratio.

2.2 Alternative Composite Backings

2.2.1 KM2/SS Hybrid

In past experiments, it has been shown that support of the ceramic material provides increased ballistic performance. Using KM2 fabric impregnated with vinyl-ester (VE) resin to provide support as well as ballistic resistance, we investigated a KM2 VE/SS hybrid. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.2 KM2/SS/KM2 Hybrid

The use of the KM2 (film stacked with polyurethane) behind the SS was thought to provide a stiffer alternative to the all SS back face. Using KM2 fabric impregnated with VE resin to provide support as well as ballistic

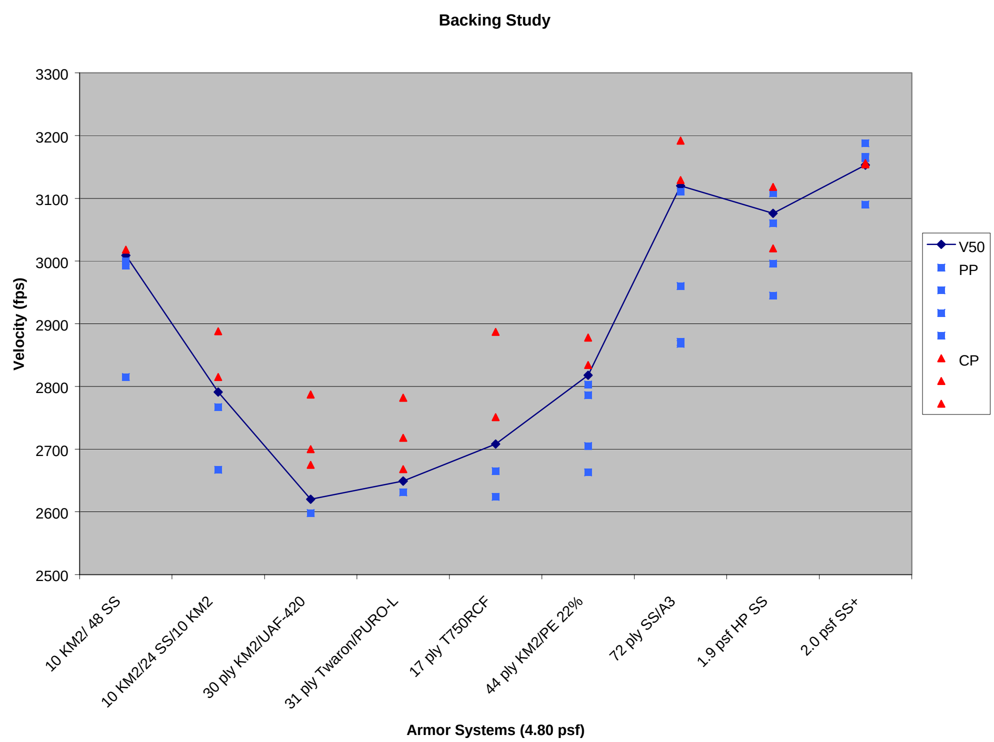

Figure 3. Threat A laminate backing study.

resistance, SS to provide a tough middle layer, and KM2 polyurethane as a stiff ballistic back face, we tested a KM2 VE/SS/KM2 polyurethane film stack hybrid. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.3 KM2 Polyurethane Film Stack Laminate

The use of the KM2 (film stacked with polyurethane) will provide a stiff, supportive yet ballistically viable, composite backing. We tested a KM2 polyurethane film stack laminate. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.4 Twaron Polyurethane Film Stack Laminate

The use of the Twaron (film stacked with PURO-L polyurethane) will provide a stiff, supportive, yet ballistically viable, composite backing. The Twaron material is lower in cost compared to the KM2 style 705 material. We tested a

Twaronpolyurethane film stack laminate. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.5 Twaron Spall Liner (Rubberized Resin)

The use of the Twaron spall liner (with rubberized resin) will provide a stiff, supportive, yet ballistically viable, composite backing. We tested a Twaron spall liner laminate. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.6 KM2 Polyethylene Film Stack

The use of the KM2 (film stacked with polyethylene) will provide a stiff, supportive, yet ballistically viable, composite backing. We tested a KM2 polyethylene film stack laminate. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.7 SSC-A3 Ceramic Material

M Cubed produces several different versions of the reaction bonded silicon carbide material. To this point, we had been using the SSC-A1 material, which has a nominal silicon carbide content of 77%. The SSC-A3 material has a nominal silicon carbide content of 82%, and as such could result in improved ballistic performance. We tested an SSC-A3/SS armor system. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.8 Ultra-High Pressure SS

In past experiments, it has been shown that the use of ultra-high-pressure processed SS material (2500 psi) provides increased ballistic performance. Using preconsolidated laminate supplied by an outside vendor, we investigated an ultra-high-pressure SS armor system. This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the

back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.2.9 Ultra-High-Pressure SS Plus

We wanted to investigate the ultra-high-pressure processing of the SS Plus material being offered by Allied Signal. The laminates were processed by the same outside vendor who supplied the ultra-high-pressure SS laminates discussed in the previous section. The only point of discussion with the SS Plus laminates is that the laminates supplied were 2.0 psf as opposed to 1.9 psf (which were requested). This testing was performed on a clay backing using a 28-ply 600 denier KM2 OTV simulant between the back face of the target and the clay block. The test sample was six targets used to obtain a V_{50} with the threat A projectile. The data was then plotted against the other armor system backing options and is shown in Figure 3.

2.3 V_0 Verification Testing

After the laminate backing study was complete, we determined that the best candidate armor systems were SS based. While the ultra-high-pressure test specimens showed the highest V_{50} results, we determined that the added cost associated with producing these laminates to the SAPI configuration would be too high to support the Interceptor program. Therefore, we concentrated on the lower pressure (150-psi) SS PCR-based* armor systems using the SSC-A1 and SSC-A3 ceramic strike faces. We fabricated 12 SAPI plates, 6 of which were made with 0.173-in SSC-A1 material and 78 plies of SS PCR; the other six were made with 0.173-in SSC-A3 and 76 plies of SS PCR. Both armor systems had areal densities of 4.85 psf. The differences in the ply counts for the two armor systems can be attributed to the different densities of the two ceramic materials (i.e., the SSC-A1 is lighter than the SSC-A3). All 12 test samples were processed at lower pressure (150 psi) in reusable silicon rubber autoclave bags. All 12 test samples had the production durability covers and nylon spall shield attached prior to testing. The verification test results for the SSC-A1 material are summarized in Tables 2 and 3. The verification test results for the SSC-A3 material are summarized in Tables 4 and 5.

*Spectra Shield PCR is a Honeywell Company registered trade name for ballistic laminates.

Table 1. SSC-A1 threat A V_0 testing.

Serial No.	Velocity (fps)	Obliquity (°)	Result	BFD	Comment
032000VF-1	2696	0	PP	1.25	Durability
032000VF-1	2670	0	PP	1.25	Durability
032000VF-1	2797	60	PP	1.12	Durability
3020VF#3	2767	0	PP	1.38	Durability
3020VF#3	2760	0	PP	1.38	Durability
3020VF#3	2738	60	PP	1.12	Durability
032000VF-6	2797	0	PP	1.38	
032000VF-6	2800	0	PP	1.25	
032000VF-6	2787	60	PP	1.00	
032000VF-5	2773	0	PP	1.38	
032000VF-5	2785	0	PP	1.25	
032000VF-5	2786	30	PP	1.38	

Notes: BFD = back face deformation.
PP = partial penetration.
CP = complete penetration.

Table 2. SSC-A1 threat B V_0 testing.

Sample	Velocity (fps)	Obliquity (°)	Result	BFD	Comment
030800VF-2	2339	0	PP	1.12	
030800VF-2	2344	0	PP	1.12	CP on insert
030800VF-2	2351	30	PP	1.12	
3020VF#4	2328	0	PP	1.12	
3020VF#4	2327	0	PP	1.12	
3020VF#4	2319	30	PP	1.12	

Table 3. SSC-A3 threat A V_0 testing.

Serial No.	Velocity (fps)	Obliquity (°)	Result	BFD	Comment
33000VF-1	2754	0	PP	1.37	Durability
33000VF-1	2797	0	PP	1.37	Durability
33000VF-1	2795	30	PP	1.37	Durability
33000VF-2	2788	0	PP	1.37	Durability
33000VF-2	2767	0	PP	1.37	Durability
33000VF-2	2786	30	PP	1.37	Durability
412000VF-6	2791	0	PP	1.25	
412000VF-6	2732	0	PP	1.37	
412000VF-6	2795	30	PP	1.37	
412000VF-5	2767	0	PP	1.37	
412000VF-5	2754	0	PP	1.37	
412000VF-5	2789	30	PP	1.50	

Table 4. SSC-A3 threat B V_0 testing.

Sample	Velocity (fps)	Obliquity (°)	Result	BFD	Comment
412000VF-4	2317	0	PP	1.12	
412000VF-4	2318	0	PP	1.00	
412000VF-4	2287	30	PP	1.00	
412000VF-8	2294	0	PP	1.12	CP on insert, 1 ply KM2
412000VF-8	2313	0	PP	1.00	
412000VF-8	2315	30	PP	1.12	

3. Conclusions

We determined that the optimum tile-to-laminate ratio for threats A and B was 60% tile and 40% laminate by weight. This correlates to an armor system of 0.170- to 0.180-in tile with 76 plies of SS PCR. The testing of the different laminate systems proved that the SS PCR-based armor system is the most desirable from a cost and performance standpoint. The ceramic material of choice is the SSC-A3 material, based on performance and manufacturing economies. Our internal verification testing and subsequent First Article Testing (FAT) at the U.S. Army Aberdeen Test Center (ATC) have validated this armor system as meeting the requirements of the Interceptor SAPI performance requirements.

Table 5. SSC-A3 threat B V_0 testing.

Sample	Velocity (fps)	Obliquity (°)	Result	BFD	Comment
412000VF-4	2317	0	PP	1.12	
412000VF-4	2318	0	PP	1.00	
412000VF-4	2287	30	PP	1.00	
412000VF-8	2294	0	PP	1.12	CP on insert, 1 ply KM2
412000VF-8	2313	0	PP	1.00	
412000VF-8	2315	30	PP	1.12	

3. Conclusions

We determined that the optimum tile-to-laminate ratio for threats A and B was 60% tile and 40% laminate by weight. This correlates to an armor system of 0.170- to 0.180-in tile with 76 plies of SS PCR. The testing of the different laminate systems proved that the SS PCR-based armor system is the most desirable from a cost and performance standpoint. The ceramic material of choice is the SSC-A3 material, based on performance and manufacturing economies. Our internal verification testing and subsequent First Article Testing (FAT) at the U.S. Army Aberdeen Test Center (ATC) have validated this armor system as meeting the requirements of the Interceptor SAPI performance requirements.

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